Demonstrating Low-Power Distributed Queuing for Active RFID Communications At 433 MHz

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***Abstract*—This paper presents a demonstrator of Low-Power Distributed Queuing (LPDQ), a MAC protocol targeted at active RFID systems operating at 433 MHz. LPDQ is based on a packet-based Preamble Sampling for network synchronization and Distributed Queuing for channel access. Compared to the MAC protocol defined in the ISO 18000- 7 standard, based on an analog Preamble Sampling and Frame Slotted ALOHA, LPDQ represents a major breakthrough in terms of system performance and energy consumption. At the MAC layer system performance is close to the optimal, e.g., 100%, and tag energy consumption can be reduced up to 50% compared to FSA.**

I. Introduction

Active Radio-Frequency IDentification (RFID) systems operating at 433 MHz are standardized under ISO 18000-7 [1], which is based on an analog Preamble Sampling (PS) to wake up tags and Frame Slotted ALOHA (FSA) to manage access to the shared medium. However, it is well-known that the analog PS is not energy efficient [2] and that the maximum performance of FSA is bounded to 36.8% due to the effects of contention [3]. Moreover, such efficiency can only be achieved when the number of slots per frame is equal to the number of tags, which is unknown a priori. Over the last decade different proposals have been made to improve the performance of FSA in RFID systems [4]. The first approach is to adapt the number of slots per frame based on estimating the tag population from collisions, e.g., double the number of slots per frame if the number of collisions is high. The second approach is to build a query tree based on subsequently querying a sub-group of tags, e.g., first discover the tags and then query each tag independently to avoid collisions. However, both approaches do not achieve a high system performance and low energy consumption due to the time and energy required to estimate the number of tags or build the query tree.

Considering that, we have designed and implemented Low-Power Distributed Queuing (LPDQ), a Medium Access Control (MAC) protocol for active RFID systems operating at the 433 MHz band. LPDQ is based on a packet-based PS [2] to achieve tag synchronization and Distributed Queuing (DQ) [5] as the channel access mechanism. In DQ time is organized into fixed-length slots, with each slot having three subperiods (e.g., access request, data transmission and feedback information), and channel access is organized using two queues, the Collision Resolution Queue (CRQ) and the Data Transmit Queue (DTQ). The CRQ ensures that tags that collide during access request subperiod are subsequently organized into sub-groups, whereas the DTQ ensures that only the tag at the head of the queue can transmit during the data transmit subperiod. Finally, a set of rules is used to manage access to both queues, e.g., a tag cannot transmit in the access request subperiod if the CRQ is not empty. For a detailed overview of the DQ operation please refer to [6].

There are two main benefits of using LPDQ. On the one hand, the packet-based PS contains the time at which the tags are expected to wake up, so tags can go back to sleep as soon as a PS packet is received. Compared to the analog PS mechanism of ISO 18000-7, where tags have to listen for the whole duration of the analog preamble, this enables to save energy on tags. On the other hand, the DQ channel access mechanism ensures that the system operates without contention during data packet transmission regardless of the number of tags. Compared to FSA in ISO 18000-7, this enables a system performance close to 100% and to reduce the energy consumption of tags by up to 50% [7].

II. Demonstrator

The demonstrator is composed of up to 30 active tags and an reader connected to a computer that acts as the system manager, as shown in Figure 1. Both the reader and the tags are based on OpenMote-433, a low-power wireless platform build using COTS (Commercial Off-The-Shelf) hardware. Specifically, OpenMote-433 is based on a Texas Instruments CC430 SoC (System on Chip), which embeds an MSP430 16-bit RISC microcontroller, running at 16 MHz with 4 kBytes of RAM and 32 kBytes of Flash memory, and a CC1101 radio transceiver, which operates at Sub-GHz bands with data rates of up to 600 kbps and support for amplitude (ASK, OOK) and frequency (FSK, MSK) modulations. The radio transceiver is tuned to the 433 MHz band using a discrete balun and connected to a $\lambda/4$ monopole antenna through an SMA connector. Finally, two AAA batteries provide energy (3 V, 1500 mAh) to the tags.

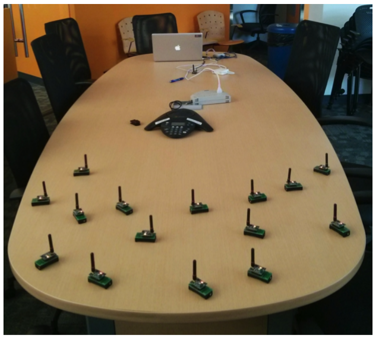

Fig. 1: Demonstrator with 15 active tags and an reader connected to a computer, which acts as the system manager.

Regarding the software, the demonstrator is build using two components. First, the firmware that runs on both the tag and the reader is written in C and provides the implementation of both FSA and LPDQ, as well as other basic functionalities (e.g., random number generation, cyclic redundancy check, etc.). Second, the software that runs in the computer is written in Python and manages the active RFID system and presents the system performance and energy consumption results, as depicted in Figure 2. The software allows the user to select which channel access mechanism to test, e.g., FSA and LPDQ, and the duration of each test. In case of selecting FSA, the software also allows to select the number of slots per frame.

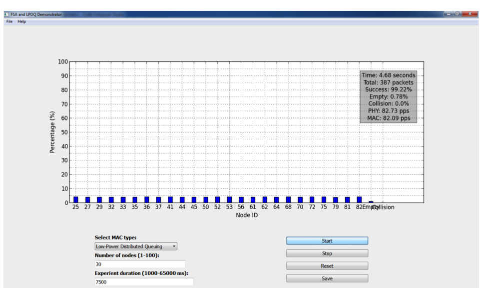

Fig. 2: User interface to manage the RFID system and show the system performance and energy consumption.

Each test consists of two phases, network synchronization and data collection. Tags are in preamble sampling mode, where they periodically enter the receive mode for a short period of time to detect wake-up packets from the reader. When triggered by the manager, the reader transmits a series of wake-up packets, which allows tags to synchronize. Once tags wake up, the data collection phase begins. In the data collection phase each tag executes the configured channel access mechanism and transmits a given number of packets to the reader. Once the packets have been transmitted the tag goes back to preamble sampling mode.

The results obtained with the demonstrator, depicted in Figure 3, show that LPDQ outperforms FSA standard in terms of system performance, e.g., packet success and collision rates. Essentially, LPDQ achieves a system performance that is optimal at the MAC layer, e.g., close 100%, as there are no collisions during data packet transmission. This, in turn, can reduce the energy consumption of tags by up to 50% because no energy is wasted due to data packet retransmission. Moreover, there are two additional benefits of LPDQ compared to the mechanisms to improve FSA described earlier. First, the system performance is independent of the number of tags, e.g., it is not necessary to adjust the number of slots per frame based on the number of collisions. Second, the collection time is reduced because collision resolution and data transmission are interleaved in time, e.g., it is not necessary to wait until the query tree is completely build to start receiving data packets from tags that are already in the DTQ.

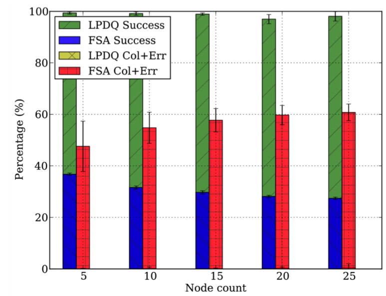

Fig. 3: System performance of LPDQ and FSA depending on the number of tags using the active RFID demonstrator.

III. Conclusions

LPDQ is a MAC protocol for active RFID systems at 433 MHz. Given the system performance and energy consumption results, and considering the fact that it can be implemented using off-the-shelf hardware, we believe that LPDQ can have a significant impact on future active RFID systems.

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